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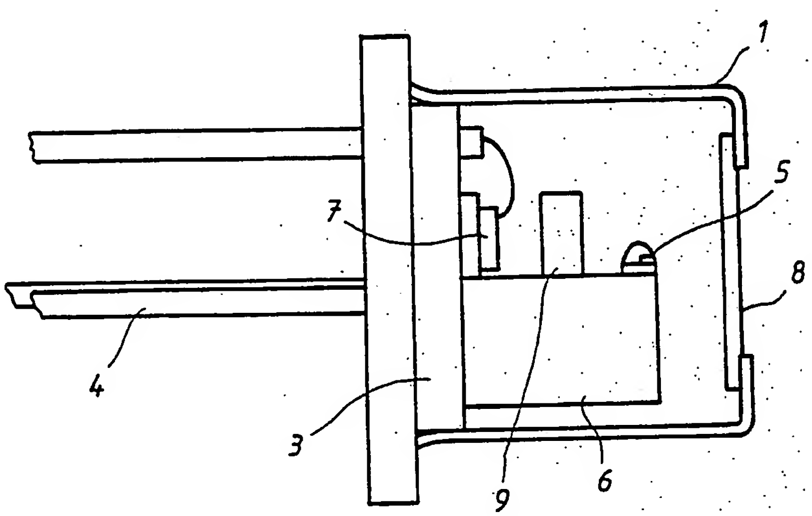
(54) Title: LASER DIODE WITH BUILT-IN SIGNAL DETECTOR



(57) Abstract

A laser diode supplemented with a filter (9) between a laser crystal (5) and a monitor diode (7), so that the monitor diode (7) can be used as a detector for light, incident upon the laser diode, of another wavelength than that emitted by the laser crystal (5). The filter (9) has the property that it reflects or absorbs that light which the laser crystal (5) present in the laser diode emits inwards towards the monitor diode (7) and transmits light of other wavelengths. As detector for the received light the existing monitor diode (7) is utilized or, if space is provided within the laser diode package, a photodiode intended for that purpose. The built-in filter (9) is mounted separately between the detecting monitor diode (7) and the laser crystal (5) or is applied as a thin filter substrate directly on the surface of either this detecting monitor diode (7) or the laser crystal (5). A modified laser diode according to the invention is used as the only active component during simultaneous transmission and reception of signals in connection with an optical fibre.

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Laser diode with built-in signal detector

TECHNICAL FIELD

The device described in the following relates to fibre-optic communication systems and especially to coupling elements for transforming electrical signals into light signals and vice versa in fibre connections.

BACKGROUND ART

Bidirectional transmission of light signals via optical lines betweeen two end points disposed at different locations may be accomplished with the aid of two separate optical fibres. Each fibre is then utilized for transmission in opposite directions. This method makes possible simultaneous transmission in both directions, so-called full-duplex communication, and gives a very high degree of isolation between the two transmission channels. However, the method is disadvantageous as it requires two fibres as well as a transmitter and receiver for each fibre, resulting in increased costs and space requirements.

There is a possibility to utilize a single optical fibre for simultaneous transmission in both directions by so-called bidirectional wavelength-multiplexed systems. The transmitter at one fibre end emits light of the wavelength λ_1 and the associated photodetector, the receiver, receives light of another wavelength λ_2. At the other end of the fibre, another photodetector detects the light of the wavelength λ_1 and the associated light source emits at the wavelength λ_2. Problems which then arise are to be able, at each end, to couple both the light transmitter and the light detector to one single optical fibre, and to optically isolate the transmitter and the associated photodetector from each other.

Normally, full-duplex systems are provided with a beam splitter to couple the radiation from the fibre to the photodetector and from the light source to the fibre. Each passage through the beam splitter entails a loss of light effect of the beam.

Bidirectional fibre-optic systems may also be used in applications where light flux in one direction originates from backscattering of light which originally was emitted in the opposite direction. For example, different types of acceleration and temperature sensors use a sensing element which luminesces in proportion to sensed changes in the sensor caused by the monitored conditions. The luminesced light is of a different wavelength and is sent back through the fibre.

A bidirectional fibre-optic device with only one fibre for communication is disclosed in US Patent 4,709,413. This patent describes a coupling device in which a light source is coupled through a hole with a small diameter in the active surface of a photodiode into the core of an optical fibre with a larger diameter than the hole. Part of the light which comes out of the fibre hits the photodiode which surrounds the hole. The photodiode may then receive light emitted in the opposite direction. This design has limitations as it requires a special design of the optical fibre and is assembled from discrete components into a unit. In addition, a certain amount of crosstalk occurs between the channels when light is reflected in the end surface of the optical fibre and other joints in a direction towards the photodiode.

SUMMARY OF THE INVENTION

One method for transmitting light into an optical fibre is to use a laser diode. By modifying a laser diode so that it both transmits light of a certain wavelength and detects light of another wavelength, an active component for both of

these purposes is obtained - a component which could be supplied in different standard designs. If a laser diode of standard design is supplemented by a filter between the laser crystal and the monitor diode, where the filter reflects or absorbs the radiation emitted inwardly by the laser crystal, the monitor diode may be used as a detector for light of a different wavelength than that of the light emitted by the laser crystal itself. In this way, such an active component is obtained for simultaneous transmission and reception of light at mutually different wavelengths.

A conventional semiconductor laser is built into a hermetically sealed package of standard size consisting of a cap fixed to a header through which connecting pins lead to the inner units. On a cooling body connected to the header, a laser crystal is mounted. The laser crystal emits light from two mirrors at the ends of a laser cavity. In this way, equal amounts of light are emitted in two directions from the cavity. One beam is directed straight inwards towards the header, where a photodiode is mounted. The other beam passes out through an opening, provided with a window, in the package of the laser diode. The photodiode is utilized for monitoring the optical output power of the laser crystal and is therefore named monitor diode.

By mounting a filter with a certain characteristic between the laser crystal and the monitor diode, the monitor diode may be used for detection of light of another wavelength than that of the laser crystal, i.e. the emitted light of the laser diode itself. The task of the filter is to prevent light from the laser crystal from reaching the monitor diode. This filter may, for example, be an interference filter. Depending on whether the light to be detected by the modified laser diode has longer or shorter wavelength than that of the emitted light, the filter may be a low-pass filter or a short-pass filter. Also a bandpass filter may be used if the pass band is sufficiently wide in relation to the bandwidth of the light to be detected.

The location of the filter between the laser crystal and the photodiode is of great importance for the desired function. The filter may be designed as a separate substrate in thin glass, where the active filter component has been applied as a coating onto the glass surface by vaporization of the filter material. With this method an attenuation of the laser light, directed backwards, by 20 dB has been measured. This is a much lower value than what is theoretically possible by comparison with current data for the filter. The reason for the inferior experimental result is that part of the light from the laser crystal is reflected towards the inner surface of the package and reaches the monitor diode.

A better result can be obtained if the interference filter is vaporized directly on the surface of the photodiode which has been mounted as a monitor diode. Another possibility is to vaporize the filter directly on the mirror of the laser crystal which is facing the monitor diode or, possibly, on both the monitor diode and the laser crystal. A further way to improve the attenuation of the laser light is to mount a thin plate of an absorbing material between the laser crystal and the monitor diode. The material in this plate may be coloured glass or, still preferably, GaAlAs whose bandwidth may be adapted for absorption of the wavelength of the laser light in question.

In this connection it may be mentioned that the residual light from the laser crystal, which after attenuation reaches the monitor diode, is utilized for the necessary control of the laser crystal.

As mentioned above, the experimentally attained attenuation is relatively low compared with the theoretically expected and lower than what is required in many applications. An explanation of this is given by the fact that the transmittance for an interference filter is changed according to the angle of incidence of the incident light.

This is determined by a displacement towards a shorter wavelength of the so-called cut-on wavelength, i.e. the wavelength at which the transmittance in the filter is 5% of the maximum. This wavelength displacement is given by the formula:

$$\lambda = \lambda_{cut\text{-}on} \sqrt{1-(n_o/n_i)^2 \sin^2\theta}$$

where $\lambda_{cut\text{-}on}$ is the cut-on wavelength in case of normal incident light;
λ is the new displaced cut-on wavelength;
n_o is the refractive index outside the filter;
n_i is the weighted refractive index for the interference filter; and
θ is the angle of incidence of the light.

This formula is valid primarily for small angles but the tendency is the same also for greater angles of incidence. From this follows that a larger proportion of that light, which is reflected and hits the filter at a greater angle of incidence is transmitted.

The filter characteristic may be adapted to the centre wavelength and scattering angle of the laser so that almost 100% of the light emitted from the laser crystal is reflected towards the filter. Unfortunately, the control of the ray path of the light is lost after the reflection.

Unless the ray path of the light can be controlled after the reflection towards the filter, this fact limits the possible degree of isolation between the laser crystal and the monitor diode. To circumvent this undesired effect, an absorption filter, possibly in combination with an interference filter, may be used. The advantage of an absorption filter is that the light is absorbed in a controlled manner. A disadvantage is that a relatively thick filter is needed to attenuate the light to the same high degree as a corresponding interference filter. If such

a filter is to be accomodated between the laser crystal and the monitor diode in a package of type TO-46 or the like, the filter must be applied directly against the surface of the monitor diode. Further, the filter must be thin. By using a semiconducting material with a bandgap the energy of which is half-way between the energy of the laser light and the light of the signal which is to be detected, a very thin filter with a steep absorption curve is obtained. Possible materials are layers of $Ga_{1-x}Al_xAs$ for absorption of shorter wavelengths and $Ga_{1-x}In_xAs_{1-y}P_y$ for longer wavelengths with different contents of aluminium and indium/phosphorus, respectively, for obtaining the desired bandgap. The layer preferred may be glued to the monitor diode or applied even at the manufacturing stage. In this design it is suitable to incorporate two photodiodes, one with a filter and one without a filter, and this in order not to lose the function of a monitor diode.

By using a so-called DIL (Dual in Line) package, larger space for the laser crystal and the photodiode with filter is obtained. This design provides space for both an absorption filter and an interference filter. A Peltier cooler may also be included, on which the laser crystal is applied. Integration of a Peltier element is a great advantage since the life of the laser crystal may be considerably increased by cooling of the same. The laser crystal, the monitor diode and the photodiode are in this case mounted on so-called chip carriers.

The field of use of this invention may be within full-duplex communication via one single optical fibre - with lasers of different transmission wavelengths and with filters of various characteristics - or in sensor applications where other types of active or passive components are currently used. The device is also suitable in measuring equipment in which laser light is emitted in one direction in the fibre only whereas, in a monitoring unit, luminescence is utilized

for returning information in a signal at a different wavelength.

In case of mass production and standardization, the laser diode in this invention may be made inexpensive. Only one fibre is needed for communication and less electronics is needed at each fibre connection. Standard packages may be used.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a section through a laser diode showing the principle of a laser diode modified by an interference filter.

Figure 2 shows how a laser diode in a standard package is provided with an additional photodiode which is coated with an absorption filter.

Figure 3 shows how the filter may be located in a laser diode with a DIL package.

Figure 4, finally, schematically shows how the invention can be utilized for full-duplex communication over an optical fibre.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A proposed embodiment is described with reference to Figure 1. A normal standard package 1 is mounted on a header 2 with a centering ring 3. Connection wires 4 extend through the header. The laser crystal 5 is placed at the upper end of a cooling body 6 with one cavity facing inwards towards the monitor diode 7 and the other cavity facing outwards towards the opening 8 provided with a window. The laser crystal 5 emits light of the wavelength 780 nm. Between the laser crystal 5 and the monitor diode 7 a filter 9 is attached by gluing. The filter is of interference type and

in this example substantially transmits light which has a greater wavelength than 850 nm. In this case the same photodiode must function as both monitor diode 7 for control of the laser crystal and as detector for received laser light of wavelengths exceeding 850 nm.

If space exists in the package 1, as e.g. the TO-46 package in Figure 2, an extra photodiode 10 may be accomodated, which is then used as a detector whereas the monitor diode 7 works in the normal way. The photodiode 10 is then coated with an absorption filter 11 which must be thin. The material in the filter 11 may be $Ga_{1-x}Al_xAs$, CdTe or other combinations depending on the wavelength spectrum which is to be filtered out.

Another proposed embodiment of the invention is illustrated in Figure 3. Here a DIL package 16 is used. An optical fibre 15 is fixed to the package 16. Light emitted by the laser crystal 5 is directed straight into the fibre 15. Some of this light is also captured by the monitor diode 7 which is mounted on a so-called chip carrier 12. The photodiode 10 serves as a detector by receiving light from the fibre 15. Between the laser crystal 5 and the photodiode 10 there are placed in this embodiment an interference filter 9 and an absorption filter 11 to filter out light from the laser crystal 5. Also the photodiode is mounted on a chip carrier 14. A pre-amplifier 17 for the photodiode 10 may also be accomodated. To actively cool the laser crystal 5, it is integrated with a Peltier element 13.

Figure 4 schematically shows how to obtain a link for full-duplex communication via an optical fibre. Two laser diodes 18 according to this invention are each connected to an end surface of an optical fibre 19 with intermediate lenses 20, if any. The laser crystal 21 emits light of the wavelength λ_1 which, via the fibre 19, is transmitted by the filter 23 and then received by the detector 25. The filter 23 reflects light for the laser crystal 22, which in turn emits

light in the opposition direction with the wavelength λ_2 through the fibre 19 and which is transmitted through the filter 22 to the detector 26. The filter 24 reflects light from the laser crystal 21.

CLAIMS

1. A laser diode comprising a laser crystal (5) and a monitor diode (7), **characterized in that** the laser diode is equipped with at least one filter (9, 11) which prevents the major part of the light from the laser crystal (5) from being detected by the monitor diode (7) or by at least one built-in photodiode (10).

2. A laser diode according to claim 1, **characterized in that** the filter (9, 11) is either at least one interference filter or at least one absorption filter or a combination of both of these.

3. A laser diode according to claims 1 and 2, **characterized in that** the filter (9, 11) is freely mounted between the laser crystal (5), the monitor diode (7) and the photodode (10), respectively, or directly applied as a filter layer on the laser crystal (5) and/or monitor diode (7) and the photodiode (10), respectively.

4. A laser diode according to claims 1-3, **characterized in that** the laser crystal (5) emits light of one wavelength and the monitor diode (7) and the photodiode (10), respectively, detect light of another wavelength.

FIG. 1

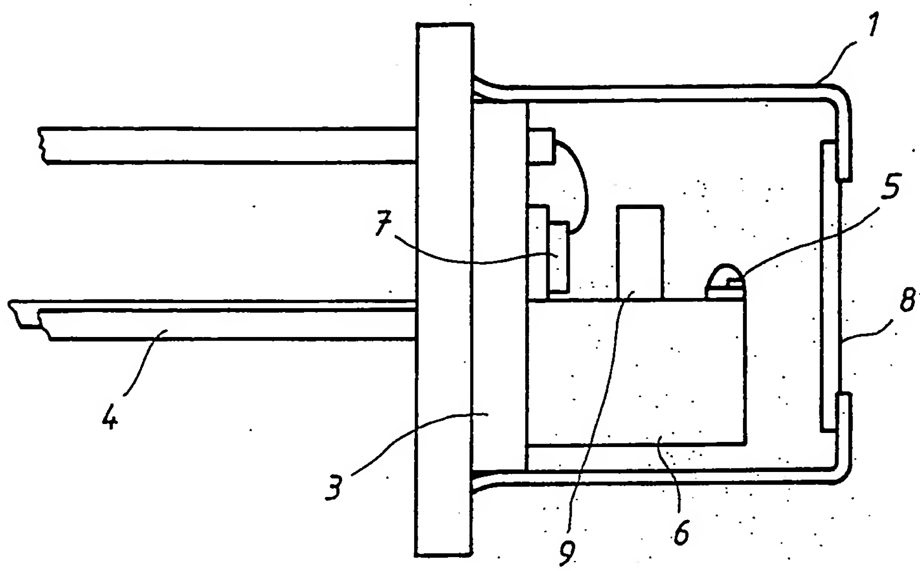


FIG. 2

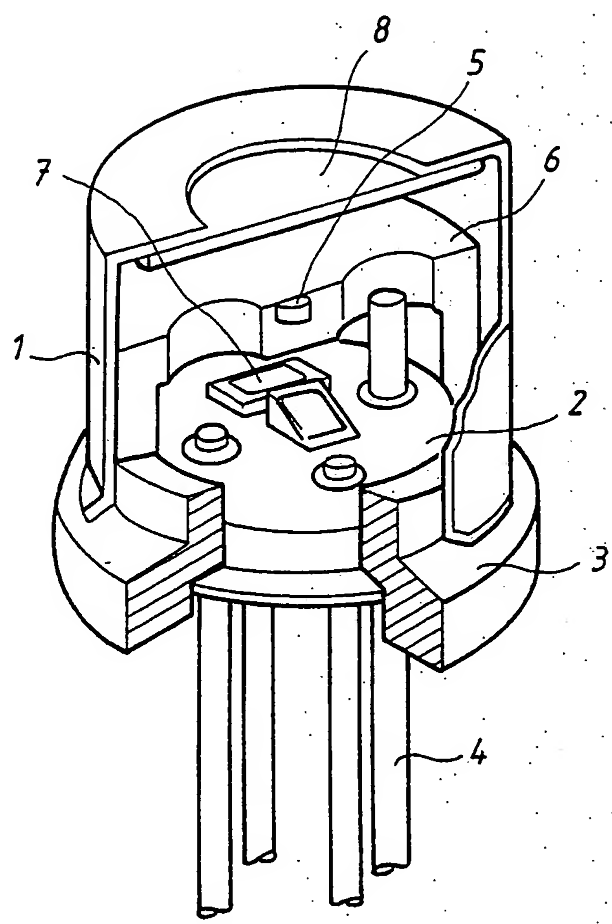


FIG. 3

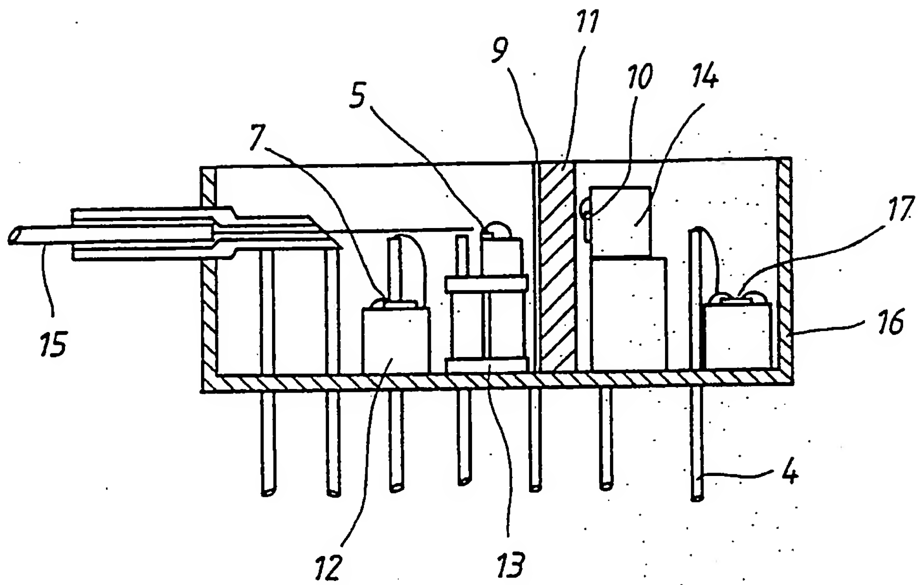
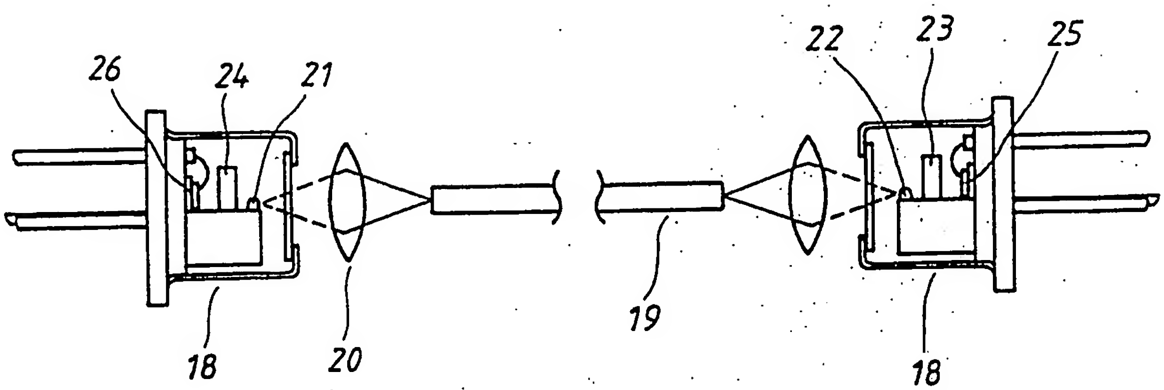


FIG. 4



INTERNATIONAL SEARCH REPORT

International Application No PCT/SE 90/00694

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC5: H 01 S 3/18

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
IPC5	H 01 S, H 04 B

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in Fields Searched[8]

SE,DK,FI,NO classes as above

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category *	Citation of Document,[11] with indication, where appropriate, of the relevant passages[12]	Relevant to Claim No.[13]
A	Patent Abstracts of Japan, Vol 7, No 21, E155, abstract of JP 57-177588, publ 1982-11-10 HITACHI SEISAKUSHO K K --	1-4
A	Patent Abstracts of Japan, Vol 10, No 332, E453, abstract of JP 61-136279, publ 1986-06-24 FUJITSU LTD --	1-4
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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
1st February 1991	1991 -02- 08
International Searching Authority	Signature of Authorized Officer
SWEDISH PATENT OFFICE	RUNE BENGTSSON

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO.PCT/SE 90/00694

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